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SID 62-1072

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DATA REPORT FOR NAA SHOCK TUNNEL TESTS (ST-4)
OF APOLLO COMMAND MODULE MODELS H-6 AND PS-6

NAS 9-150

(U)

24 August 1962

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Approved by

D. J. Gildea – Manager
Flight Technology

NORTH AMERICAN AVIATION, INC.
SPACE and INFORMATION SYSTEMS DIVISION

FOREWORD

The tests described herein were conducted
under NASA Apollo Contract NAS 9-150 during the
period from 2 May 1962 to 12 July 1962.

This report was prepared by H. Gorowitz of
the Wind Tunnel Projects Group, Los Angeles
Division.

ABSTRACT

This report contains results of heat transfer and pressure tests of the 0.01875-scale Apollo models H-6 and PS-6. The tests were conducted in the NAA 12-inch Shock Tunnel (ST-4) at Mach numbers of 15.5, 16.8, and 18.3.

Presented in this report are tabulated heat flow rates and absolute pressure data for each test condition. This report contains basic wind tunnel test data only, in order to make the test results available at the earliest possible date. Analysis and summary of results will be reported later under separate cover.

Stagnation point heating rates were also obtained on a 1.75-inch diameter sphere model.

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TABLE OF CONTENTS

I. INTRODUCTION

Shock Tunnel tests of the 0.01875-scale Apollo models H-6 and PS-6 were conducted to investigate the heat flow rate and absolute pressure distributions on the command module.

The command module was tested through an angle of attack range of 140° to 180°.

Stagnation point heat transfer tests were also performed on a 1.75-inch diameter sphere to evaluate the validity of the heating rate measurements on the Apollo command module.

Pretest information was given in Reference (a).

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II. REMARKS

PRESSURE MODEL

Acquisition of pressure data was relatively trouble free. Care was required in estimating expected pressure levels in order to avoid saturation of the carrier amplifiers due to excessive transducer signal levels. The actual calibration curves were used, rather than linear slopes, to reduce data suspected of being in the saturated region of amplifier operation.

Vibration sensitivity of the Hidyne pressure transducers was a problem in the measurement of the very low pressure level occuring in the nose cone region of the model.

HEAT TRANSFER MODEL

Erosion of the thin-film heat transfer gages due to impact of particles from the primary diaphram was a major problem. A baffle plate, which was installed at the nozzle throat entrance, reduced gage erosion by 60 per cent as measured by the resistance rise of the gage from run to run. The heat transfer test schedule was not completed due to lack of gages since the baffle plate was not fabricated and installed until late in the test. About twenty gages were destroyed by erosion during the test.

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III. MODEL DESCRIPTION

A. GENERAL

The models of the Apollo command module tested were used previously for pre-proposal studies and do <u>not</u> duplicate the current configuration.

The Pressure Distribution model was a hollow aluminum shell, in which the pressure transducers were placed. The model body was sealed and connected to a vacuum reference tank, to provide a reference pressure for the differential transducers.

The Heat Transfer model was similar to the Pressure Distribution model except that the internal cavity was not sealed, and heat transfer gages were installed flush with the surface of the model.

Both of the above models were supported by stings which exited from the nose cone at an angle of 35° to the axis of symmetry.

The calibration sphere model was fabricated from a 1.75-inch diameter plastic fishing float.

The model design drawings are listed in Section V of this report, References (b) and (c).

III MODEL DESCRIPTION – CONTINUED

B. NOMENCLATURE SKETCHES
   COMMAND MODULE C_{21}
   DRAWING Q 61-21-3 (-5)

8.0 ^{R}

160.0 ^{D}

35.0°

35°

10.48 ^{R}

192.0 ^{R}

POSITION OF MODEL STING
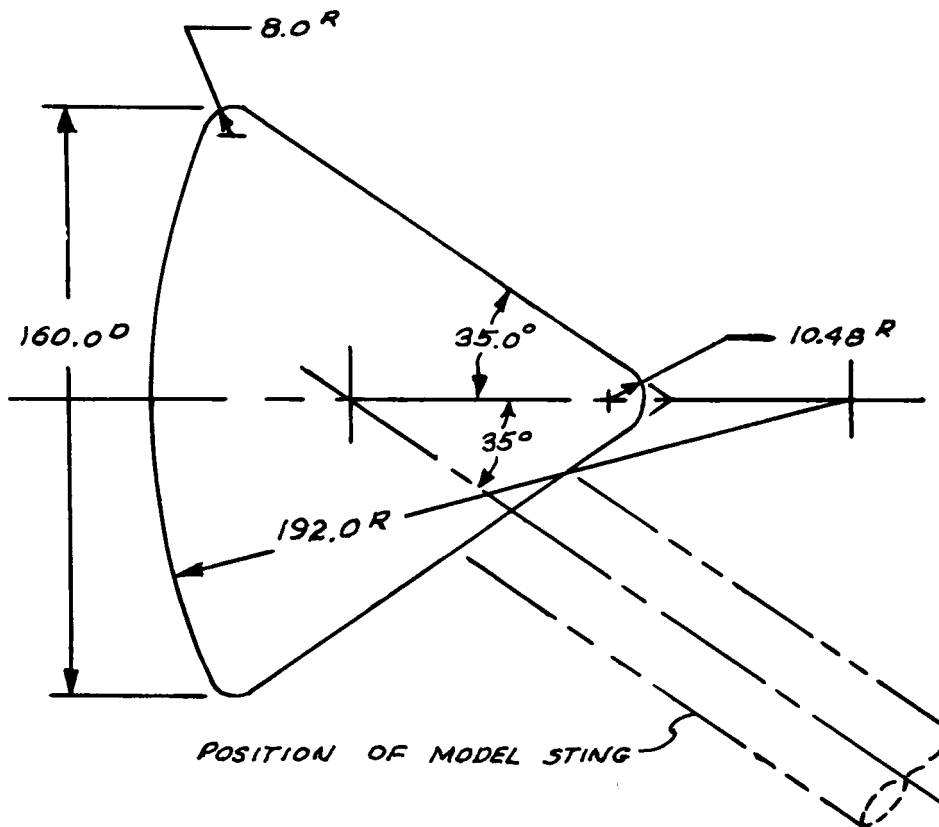
DIMENSIONS FULL SCALE, INCHES
DRAWING NOT TO SCALE

III. MODEL DESCRIPTION – CONTINUED

B. NOMENCLATURE SKETCHES – CONTINUED

CALIBRATION SPHERE

1.75 D

POSITION OF MODEL STING
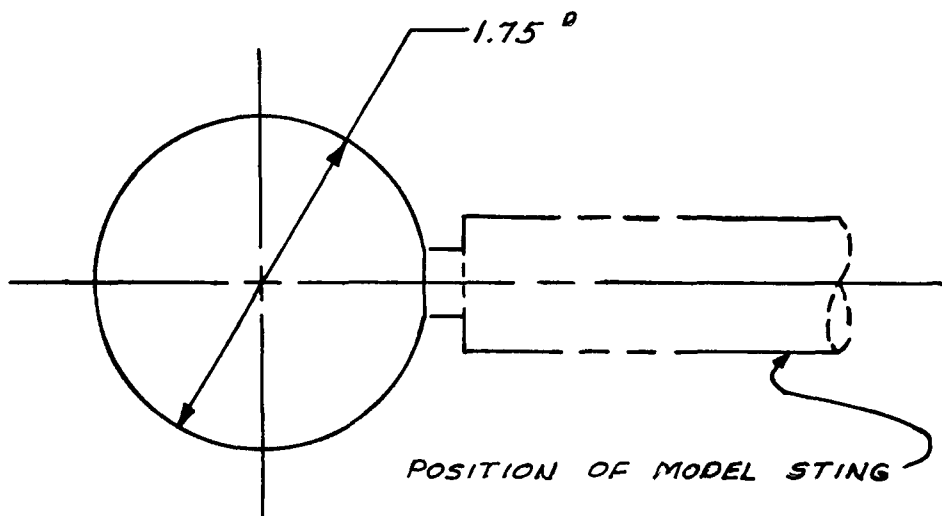
DIMENSIONS MODEL SCALE, INCHES
DRAWING NOT TO SCALE

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C. MODEL NOMENCLATURE AND FULL-SCALE DIMENSIONS

Model Factor 0.01875

Command Module, C_{21}

Maximum Diameter, in.	160.0
Radius of Spherical Blunt End, in.	192.0
Corner Radius, in.	8.0
Nose Cone Semi-angle, deg.	35.0
Nose Cone Vertex Radius, in.	10.48

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IV. TEST PROCEDURE

A. TEST NOMENCLATURE

M_o = Freestream Mach number

V_o = Freestream velocity, fps

P_o = Freestream static pressure, psia

p = Local orifice pressure, psia

q_o = Freestream dynamic pressure, psia

ρ_o = Freestream density, slugs/ft^3

μ_o = Freestream absolute viscosity, lb-sec/ft^2

H_o = Reservoir pressure, psia

T_T = Reservoir temperature, °R

T_o = Freestream static temperature, °R

h_T = Reservoir enthalpy, BTU/lb

Re/l = Reynolds number per foot

P_{T2} = Total pressure behind normal shock, psia

$\overset{\bullet}{q}$ = Heating rate, BTU/ft^2-sec

$D*$ = Nozzle throat diameter, in

s = Distance to orifice from center of pointed end of model measured along surface of model, positive on windward side, in

r = Radius of command module at maximum section, in

m = Subscript referring to particular heat transfer gage or pressure orifice location

λ = Angle of plane of instrumentation relative to pitch plane, deg

α = Angle of attack of model, $\alpha = 0°$ when pointed end of command module faces airstream, deg

B. MODEL INSTALLATION

Separate Heat Transfer and Pressure models were used during the test. Each model had its own integral sting which exited from the nose cone at an angle of 35° to the axis of symmetry.

The model face was rotated in order to obtain data at $\lambda = 45°$.

The Apollo model and sphere model installation sketches are shown in Figures (1) and (2) respectively, appendix B.

C. INSTRUMENTATION

Seven Hidyne variable reluctance, wafer-type transducers were mounted inside the Pressure model and connected to the surface pressure orifices. The electrical signals from the transducers were each transmitted via a channel of a C.E.C. 1-127 carrier amplifier to a galvanometer in a C.E.C. 1-14 direct-writing oscillograph. The inside of the model was evacuated and held constant during each run in order to provide a reference pressure for the transducers. The range of transducers used during the test were 0.5 psid and 3.0 psid.

Thin film platinum resistance thermometers fabricated by NAA were flush mounted in the Heat Transfer model to measure surface heating rates. Electrical signals from the heat transfer gages were recorded by Tektronix Dual-Beam Oscilloscopes.

The heat transfer gages were calibrated directly in terms of heat transfer rate by exposure to a radiant heat source which was initially calibrated with a secondary standard calorimeter. The emissivities of the heat transfer gages and the secondary standard calorimeter were the same.

The Calibration Sphere model was instrumented with one heat transfer gage at the stagnation point.

The following sketches and tabulations show pressure orifice locations, transducer range, and heat transfer gage locations.

IV TEST PROCEDURE – CONTINUED

C. INSTRUMENTATION – CONTINUED

PRESSURE ORFICE LOCATIONS
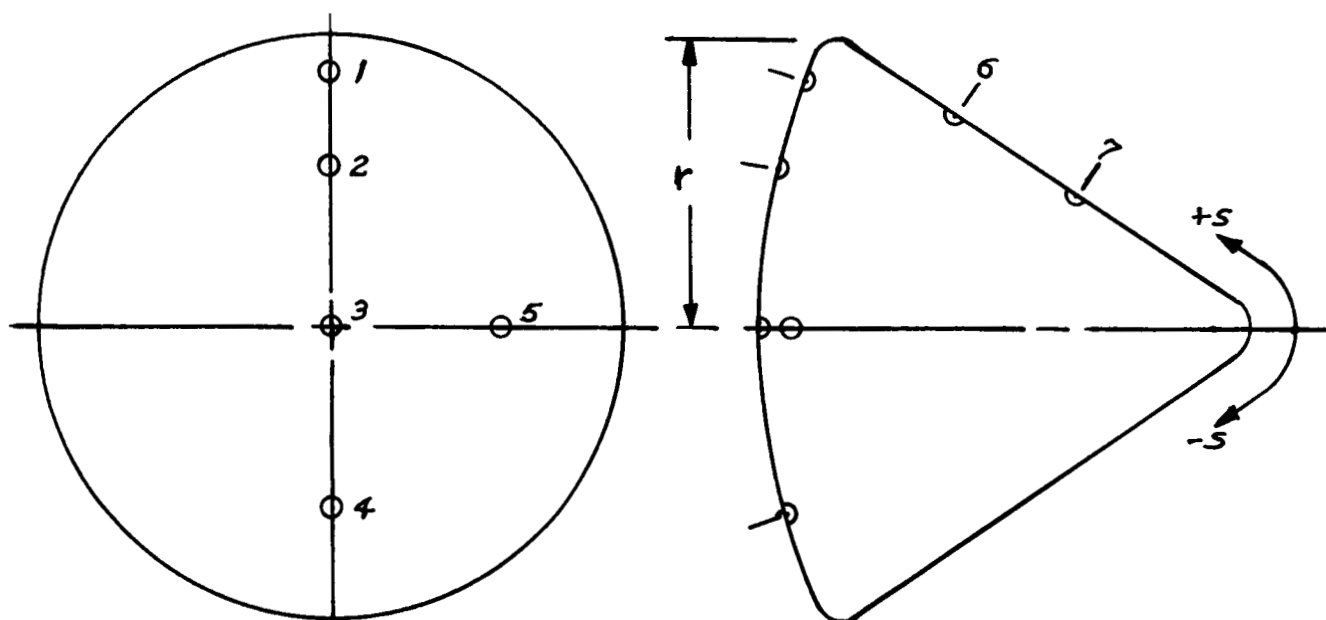
ROTATION ANGLE, $\lambda = 0°$
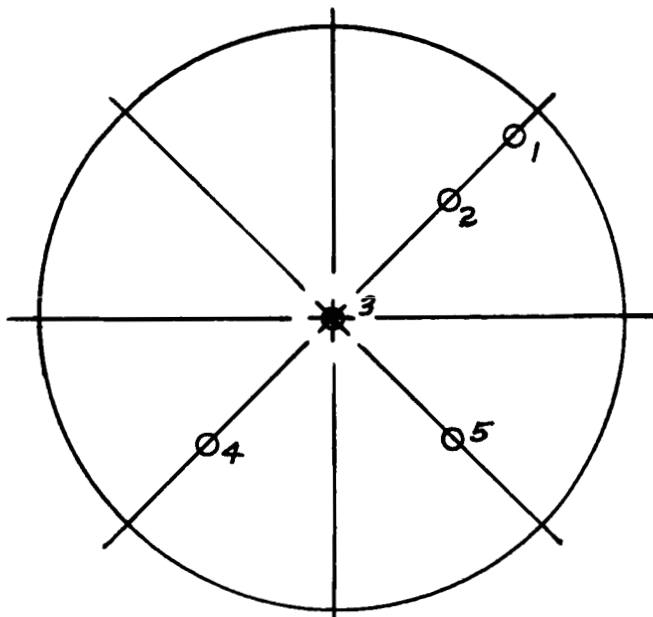
ROTATION ANGLE, $\lambda = 45°$

Orifice	s/r	RANGE (psid)
1	1.88	3.0
2	2.30	3.0
3	2.78	3.0
4	-2.15	3.0
5	2.15	3.0
6	1.28	0.5
7	0.55	0.5

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IV TEST PROCEDURE - CONTINUED

C. INSTRUMENTATION — CONTINUED

HEAT TRANSFER GAGE LOCATIONS
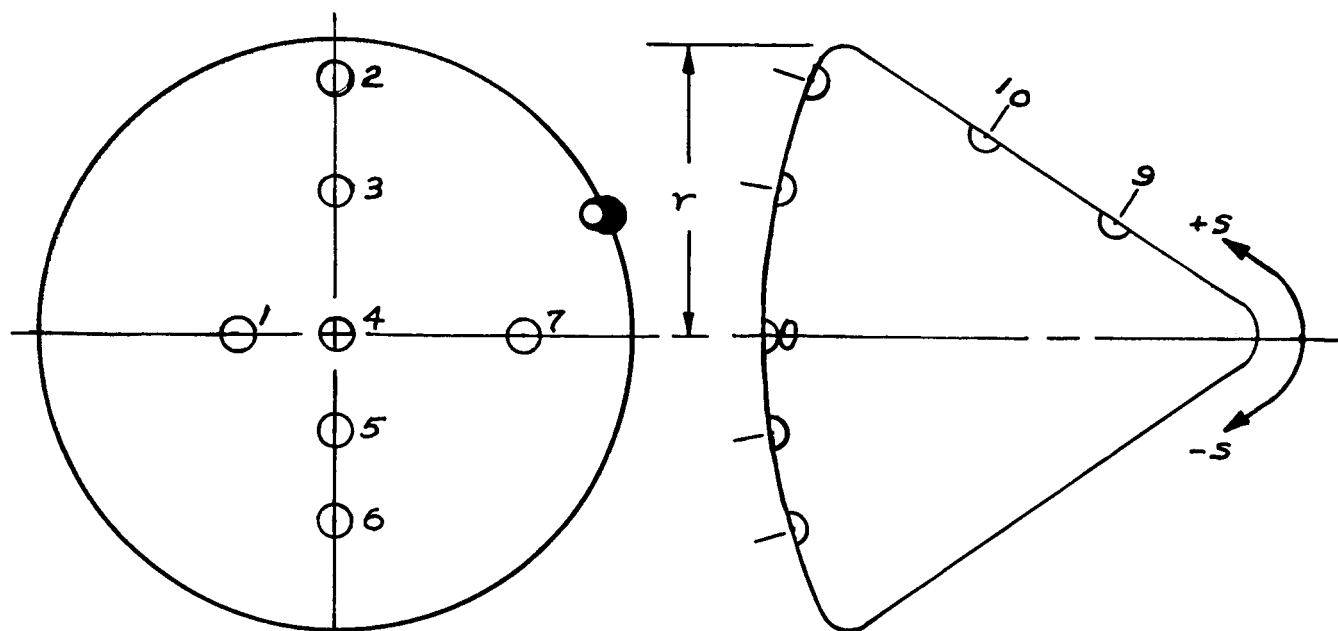
ROTATION ANGLE, $\lambda = 0°$
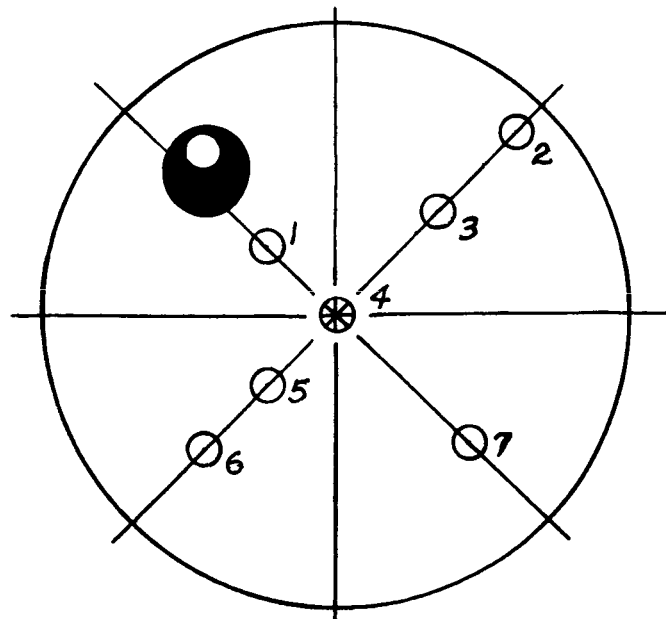
ROTATION ANGLE, $\lambda = 45°$

GAGE	S/r
1	2.46
2	1.88
3	2.29
4	2.78
5	-2.45
6	-2.11
7	2.13
9	.64
10	1.17

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D.   DATA REDUCTION

All data was reduced manually using the equations and procedures outlined in Reference (a).

It was determined after the test that the monitor pitot was mounted slightly outside of the core. Therefore, test conditions were re-evaluated from a pitot rake survey, the results of which are presented in Figure 5, appendix B.

The calibration sphere stagnation point heat transfer data are compared with Fay-Riddell Theory in Figure 6, appendix B.

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V. REFERENCES

(a) NA-62-459, "Pretest Information, NAA Shock Tunnel, Apollo .01875-Scale Pressure and Heat Transfer Models"

(b) Q 61-21-3, Heat Transfer Model, Apollo Proposal H-6

(c) Q 61-21-5, Pressure Model, Apollo Proposal PS-6

APPENDIX A

A: Shock Tunnel Test Conditions

D^* in.	M_o	H_o psia	T_T °R	h_t BTU/lb	P_o psia	T_o °R	ρ_o lb-sec²/ft⁴	V_o ft/sec	q_o psia	μ_o lb-sec/ft²	Re/1 Re/ft
0.075	18.3	2300	3364	915	$.733 \times 10^{-3}$	56.2	1.10×10^{-6}	6725	.172	4.50×10^{-8}	1.64×10^5
0.100	16.8	2300	3364	915	1.32×10^{-3}	66.5	1.67×10^{-6}	6710	.261	5.32×10^{-8}	2.11×10^5
0.125	15.5	2300	3364	915	2.30×10^{-3}	77.9	2.48×10^{-6}	6700	.387	6.32×10^{-8}	2.67×10^5

Notes: 1. All test conditions based on real gas properties
2. μ_o based on Van Driest low temperature viscosity relation

B. Pressure Data
Apollo Command Module

Run No.	M_o	$D*$ in	α deg	λ deg	H_o psia	Model Pressure, P_m — psia						
						1	2	3	4	5	6	7
1	18.3	0.075	180	0	2300	0.213	—	0.334	0.250	0.238	0.002	0.004
2	18.3	0.075	180	0	2310	0.210	—	0.301	0.260	0.238	—	0.004
3	18.3	0.075	180	0	2330	0.224	0.323	0.330	0.260	0.251	—	0.008
4	16.8	0.100	180	0	2300	0.378	0.487	0.555	0.453	0.422	0.012	0.012
5	15.5	0.125	180	0	2330	0.457	0.670	0.680	0.573	0.583	0.017	0.013
6	15.5	0.125	180	0	2310	0.482	0.665	0.660	—	0.557	0.024	0.018
7	15.5	0.125	165	0	2300	0.607	0.662	—	0.355	—	0.009	0.012
8	16.8	0.100	165	0	2300	0.405	0.510	0.455	0.265	0.395	0.004	0.007
9	15.5	0.125	165	0	2300	0.620	0.695	0.610	0.376	0.588	0.011	0.011
10	16.8	0.100	165	0	2300	0.427	0.560	0.455	0.267	0.450	0.007	0.006
11	18.3	0.075	165	0	2350	0.247	—	0.280	0.170	0.288	0.006	0.005
12	18.3	0.075	160	0	2350	0.280	0.360	0.305	0.176	0.283	0.010	0.006
13	16.8	0.100	160	0	2310	0.435	0.510	0.430	0.241	0.433	0.013	0.010
14	15.5	0.125	160	0	2300	0.633	0.695	0.635	0.300	0.620	0.017	0.012
15	15.5	0.125	155	0	2300	0.633	0.728	0.575	0.285	0.557	0.023	0.020
s/r						1.88	2.30	2.78	-2.15	2.15	1.28	0.55

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B. Pressure Data (Contd.)

Run No.	M_o	D* in.	α deg	λ deg	H_o psia	Model Pressure, P_m — psia						
						1	2	3	4	5	6	7
16	16.8	0.100	155	0	2310	0.465	0.383	0.410	0.220	0.387	0.017	0.013
17	18.3	0.075	155	0	2310	0.287	0.330	0.265	0.145	0.255	0.006	0.007
18	18.3	0.075	150	0	2330	0.287	0.313	0.230	0.086	0.228	0.015	0.008
19	16.8	0.100	150	0	2300	0.466	0.480	0.360	0.185	0.363	0.025	0.012
20	15.5	0.125	150	0	2300	0.675	—	0.520	0.278	0.525	0.036	0.012
21	15.5	0.125	140	0	2310	0.683	0.600	0.425	0.176	0.405	0.032	0.036
22	16.8	0.100	140	0	2330	0.490	0.430	0.300	0.131	0.288	0.019	0.025
23	18.3	0.075	140	0	2300	0.315	0.250	0.180	0.077	0.177	0.026	0.010
24	18.3	0.075	140	0	2260	0.293	0.250	0.170	0.075	0.172	0.025	0.054
25	18.3	0.075	140	45	2280	0.234	0.222	0.185	0.103	0.133	0.026	0.013
26	16.8	0.100	140	45	2300	0.360	0.350	0.270	0.152	0.195	0.030	0.022
27	15.5	0.125	140	45	2260	0.527	0.508	0.380	0.210	0.272	0.055	0.033
28	15.5	0.125	150	45	2250	0.537	0.630	0.535	0.295	0.397	0.034	0.013
29	16.8	0.100	150	45	2280	0.385	0.443	0.365	0.199	0.275	0.025	0.018
30	18.3	0.075	150	45	2280	0.240	0.292	0.240	0.140	0.176	0.016	0.015
					s/r	1.88	2.30	2.78	-2.15	2.15	1.28	0.55

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B. Pressure Data — (Contd.)

Run No.	M_o	D* in	α deg	λ deg	H_o psia	Model Pressure, P_m — psia						
						1	2	3	4	5	6	7
31	18.3	0.075	155	45	2280	0.221	0.292	0.255	0.161	0.196	0.013	0.010
32	16.8	0.100	155	45	2280	0.420	0.506	0.425	0.242	0.328	0.019	0.023
33	15.5	0.125	155	45	2280	0.595	0.665	0.570	0.339	0.437	0.025	0.022
34	15.5	0.125	160	45	2280	0.565	0.685	0.585	0.366	0.513	0.021	0.016
35	16.8	0.100	160	45	2310	0.393	0.518	0.440	0.263	0.377	0.014	0.008
36	18.3	0.075	160	45	2300	0.253	0.324	0.280	0.174	0.227	0.006	0.006
37	18.3	0.075	165	45	2330	0.247	0.324	0.295	0.198	0.258	0.007	0.007
38	16.8	0.100	165	45	2310	0.394	0.525	0.485	0.300	0.403	0.008	0.005
39	15.5	0.125	165	45	2330	0.600	0.740	0.690	0.425	0.590	0.011	0.008
40	15.5	0.125	180	45	2330	0.490	0.687	0.692	0.595	0.666	0.020	0.008
41	16.8	0.100	180	45	2300	0.335	0.485	0.500	0.420	0.490	0.011	0.008
42	16.8	0.100	180	45	2300	0.360	0.505	0.530	0.425	0.490	0.014	0.008
43	18.3	0.075	180	45	2300	0.217	0.307	0.330	0.244	0.315	0.015	0.007
44	16.8	0.100	150	45	2300	0.377	0.455	0.385	0.212	0.280	0.024	0.005
					s/r	1.88	2.30	2.78	-2.15	2.15	1.28	0.55

C. Heat Transfer Data
Apollo Command Module

Model Heat Transfer Rate, $\dot{q}_m$ BTU/FT^2 – SEC

Run No.	M_0	α	λ	Gage: 1	2	3	4	5	6	7	9	10
				s/r: 2.46	1.88	2.29	2.78	-2.45	-2.11	2.13	0.64	1.17
1	18.3	0	0	11.95	9.34	11.6	12.70	12.10	10.70	10.30		
3	16.8	0	0		10.8		16.62			15.90		
6	18.3	30	0	7.34	12.40		10.13	7.38	4.8	5.85		
7	18.3	25	0	8.27	11.65		9.95	7.73	5.94	5.43		
8	18.3	25	0	9.82	10.93			8.48	6.33	6.52		
10	18.3	20	0				8.45		6.07	6.95		
11	18.3	15	0		8.95		8.88	8.17	5.65	6.62		
13	18.3	15	0	6.15	11.10			4.82		4.75		
15	18.3	40	0	8.10	10.23		8.16	5.85	4.56	4.00	1.12	
16	18.3	40	45	8.96	10.5		9.20	6.15	5.40	4.35		0.77
17	18.3	30	45	9.9	10.0		11.32	9.14	10.9	6.76		
18	18.3	0	45	9.56	18.00		9.55			4.53		
19	16.8	40	45	8.36	21.80		10.20		6.30	6.45		
20	16.8	40	0									
21	16.8	30	0	10.40	19.60		9.70		7.90	8.45		

C. Heat Transfer Data (Con't)
Apollo Command Module

Model Heat Transfer Rate, $\dot{q}_m$, BTU/FT^2 - SEC

Run No.	M_0	α	λ	Gage: s/r :	1 2.46	2 1.88	3 2.29	4 2.78	5 -2.45	6 -2.11	7 2.13	9 0.64	10 1.17
22	16.8	0	0		16.40	14.45		15.50		15.75			
23	15.5	40	0		13.10	29.0		12.20		8.50	9.95		
24	15.5	30	0		15.70	25.0		14.90		10.60	11.75		
25	15.5	0	0		19.50	18.3		20.6					
26	15.5	0	45			17.35		19.0					

C. Heat Transfer Data

Calibration Sphere Model

Stagnation Point Heating Rate   BTU/ft^2 - sec.

Run	M_o (Avg.)	α	$\dot{q}$
27	18.3	0	19.4
28	18.3	0	17.5
29	16.8	0	21.2
30	15.5	0	26.7
31	18.3	0	17.5

Note: See Figure 6 for comparison of measured heating rates with theory.

APPENDIX B

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MODEL NO.

A. Installation Drawings

Q60-6-3 Support Post

Outline of Window

Support Sector
(sketch #169)

℄ Window

+ α

.95

2.60

Pitot Transducer

Point of Rotation

W/ND

Model Axis of Symmetry

FIGURE 1.
APOLLO COMMAND MODULE
INSTALLATION SKETCH

½ SIZE

ED-423

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MODEL NO.

A. *Installation Drawings—continued*

Q60-6-3 SUPPORT POST

OUTLINE OF WINDOW

PITOT TRANSDUCER

2.60

₵ WINDOW

WIND
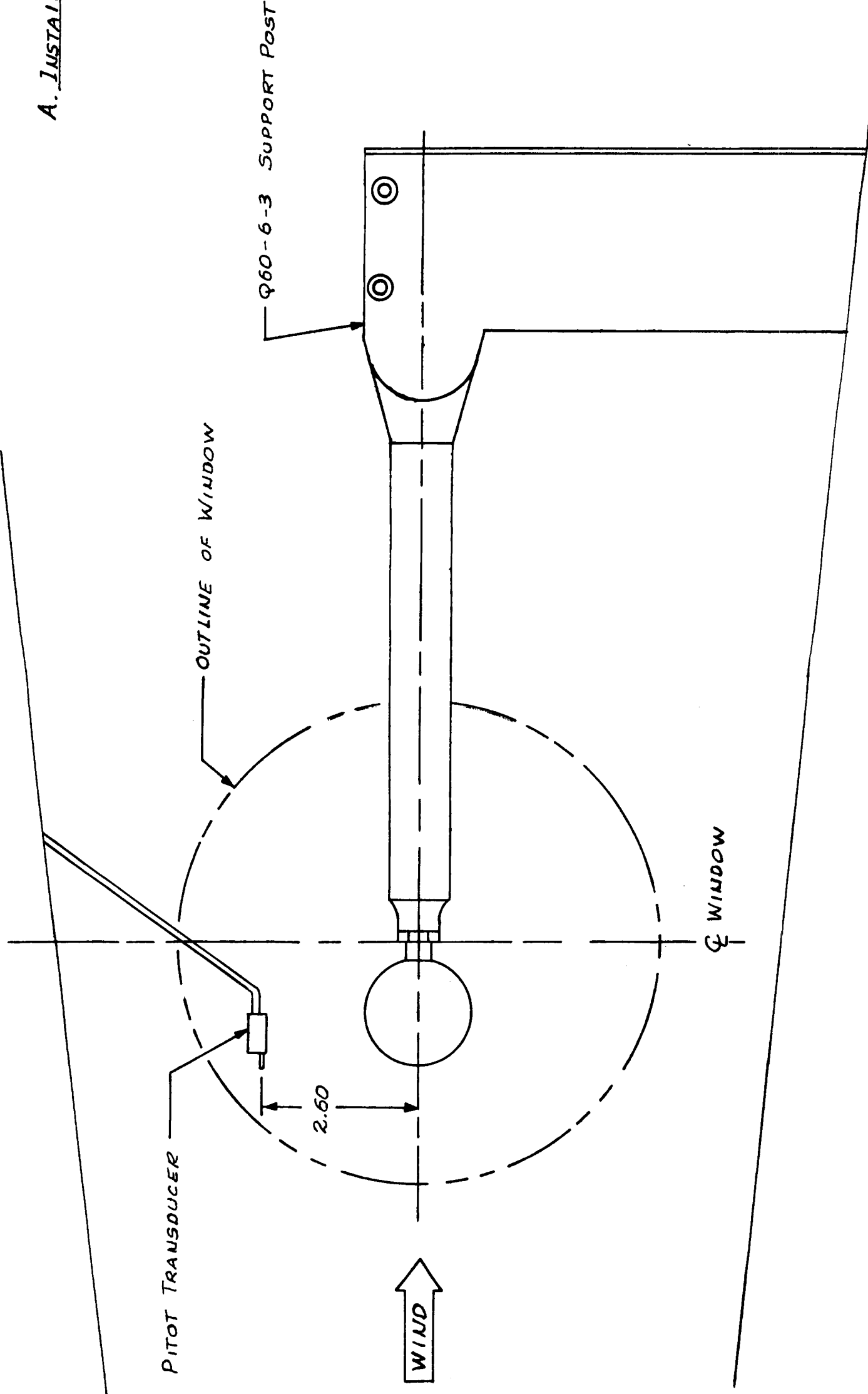
FIGURE 2.
CALIBRATION SPHERE MODEL
INSTALLATION SKETCH

½ SIZE   CONFIDENTIAL

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ED-423

FIGURE 3. Apollo Command Module (H-6) Installed In NAA Shock Tunnel
($\alpha = 180°$)
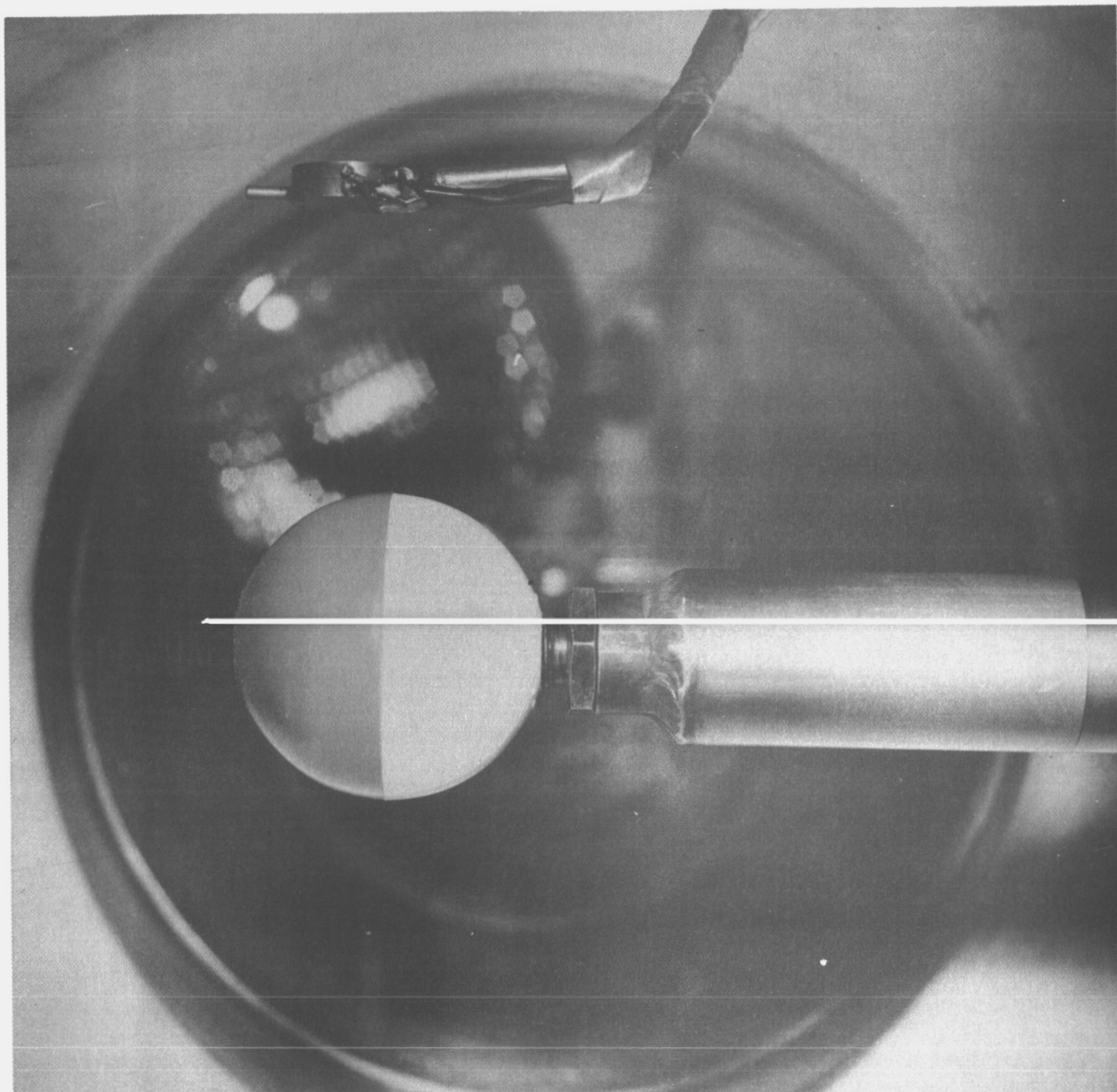
FIGURE 4.   Sphere Model Installed in NAA Shock Tunnel (α = 0°)

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MODEL NO.

C. Plotted Data

SYM.	RUN	D^*, in.
⊙	1	0.125
△	2	"
□	7	"
▽	4	0.100
◇	6	"
⍽	3	0.075
⍽	5	"

NOTE: FLAG SYMBOLS DENOTE
PITOT INDICATION AT
2.6" ABOVE CENTER OF
TUNNEL ON VERTICAL ℄.

LONGITUDINAL SURVEY PLANE 2.10 IN.
FORWARD OF WINDOW ℄.

MACH NO.

INCHES FROM VERTICAL ℄

MODEL LOCATION

FIGURE 5. NAA SHOCK TUNNEL
HORIZONTAL ℄ MACH NUMBER DISTRIBUTION

B-7
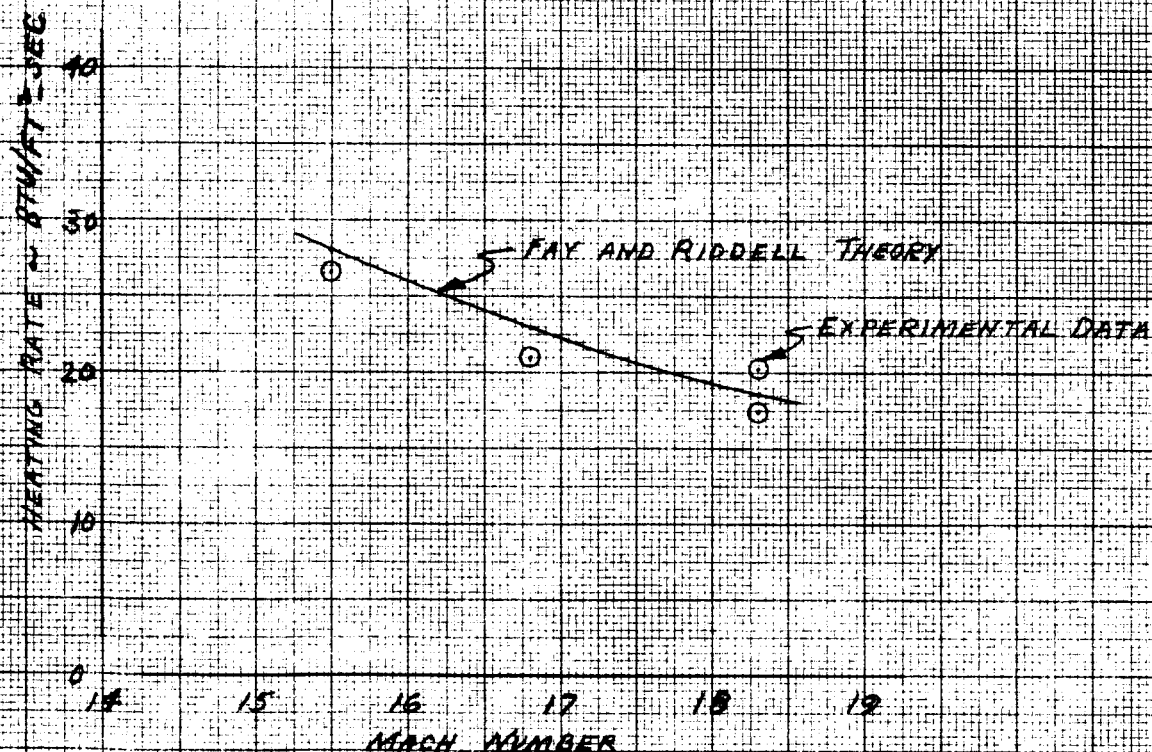
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c) Plotted Data

FIGURE 6
NAA SHOCK TUNNEL
STAGNATION POINT HEATING RATE
ON A 1.75 IN. DIA. SPHERE

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